

# A 130 GeV photon line from dark matter annihilation in the NMSSM

Debottam Das, Ulrich Ellwanger and Pantelis Mitropoulos

*Laboratoire de Physique Théorique, UMR 8627, CNRS and Université de Paris-Sud,  
Bât. 210, 91405 Orsay, France*

## Abstract

In the Next-to-Minimal Supersymmetric Standard Model, neutralino dark matter can annihilate into a pair of photons through the exchange of a CP-odd Higgs boson in the s-channel. The CP-odd Higgs boson couples to two photons through a loop of dominantly higgsino-like charginos. We show that the parameter space of the NMSSM can accommodate simultaneously i) neutralino-like dark matter of a mass of about 130 GeV giving rise to a 130 GeV photon line; ii) an annihilation cross section of or larger than  $10^{-27} \text{ cm}^3 \text{ s}^{-1}$ ; iii) a relic density in agreement with WMAP constraints; iv) a direct detection cross section compatible with bounds from XENON100, and v) a Standard Model like Higgs mass of about 125 GeV. However, the CP-odd Higgs mass has to lie accidentally close to 260 GeV.

# 1 Introduction

The fact that annihilation of dark matter can give rise to photons with a well-defined energy [1–22] has motivated searches for such gamma lines originating from the center of our galaxy by the EGRET [23], H.E.S.S. [24, 25] and Fermi LAT [26–28] experiments.

Recent analyses of the publicly available data from Fermi LAT [29–32] have discovered hints for a gamma line at  $E_\gamma \sim 130$  GeV in the form of an excess of about 3 – 4 standard deviations, assuming that the background flux can be approximated by a single power law. An interpretation of this excess as dark matter pair annihilation into a pair of photons would require a partial annihilation cross section of about  $10^{-27} \text{ cm}^3 \text{ s}^{-1}$  [30, 31].

However, more general parametrizations of the background flux [33, 34] reduce the significance of the excess, making it compatible with a diffuse background possibly of instrumental or astrophysical origin. The Fermi LAT collaboration preferred to interpret the same data only in terms of upper bounds on the partial annihilation cross section [28].

Still, future additional data could confirm the present hints for a possible excess; hence it is of interest to study whether it could be explained within concrete models for dark matter which are compatible with bounds on its relic density from WMAP [35] and bounds on its direct detection cross section (in the relevant mass range) from XENON100 [36].

Following the publication [30], different types of such models have been proposed: models with an extra  $U(1)'$  gauge symmetry where the dark matter couples only to the extra  $Z'$  gauge boson, and the  $Z'$  to photons via a Chern-Simons term [37]; models with an extra singlet and extra charged fields allowing for an enhanced branching ratio of the Standard Model-like Higgs boson into two photons [38]; extensions of the Minimal Supersymmetric Standard Model (MSSM) by right-handed neutrinos and extra Higgs doublets (with a right-handed sneutrino as dark matter) [39]; decaying dark matter in the MSSM extended by additional fields and couplings [40]; extensions of the Standard Model or the MSSM by singlets with Peccei-Quinn symmetry where dark matter can annihilate into a photon pair via an axion in the s-channel [41]; a string/M-theory motivated version of the MSSM (with an unconventional spectrum involving very heavy scalar superpartners) where wino-like dark matter can annihilate into a photon plus a  $Z$  boson [42]. (In the MSSM with bino- or higgsino-like dark matter, the annihilation cross section into one or two photons would be too small [2–5, 7].)

In the present paper we consider the simplest supersymmetric extension of the Standard Model with a scale invariant superpotential, the Next-to-Minimal Supersymmetric Standard Model (NMSSM) [43, 44]. In the NMSSM, the Higgs/higgsino mass term  $\mu H_u H_d$  in the superpotential of the MSSM is replaced by a coupling  $\lambda S H_u H_d$  to a gauge singlet superfield  $S$ . Compared to the MSSM, the Higgs sector of the NMSSM includes additional neutral CP-even and CP-odd states. It is known that a large dark matter (neutralino) annihilation cross section into two photons can arise from neutralino annihilation through the NMSSM-specific CP-odd Higgs boson in the s-channel [9, 20, 21, 41]. Moreover, due to the coupling  $\lambda S H_u H_d$  the lightest CP-even Higgs mass is naturally heavier than in the MSSM [43–48] which makes it easier to explain a Higgs mass of 125 GeV [49–59].

Hence an obvious question is whether the parameter space of the NMSSM can describe simultaneously the following phenomena: 1) A neutralino-like dark matter particle of a mass of about 130 GeV with a partial annihilation cross section into two photons of about

$10^{-27} \text{ cm}^3 \text{ s}^{-1}$  and a relic density compatible with WMAP constraints, 2) a Standard Model-like Higgs boson with a mass of about 125 GeV, but 3) respecting the upper bound of XENON100 on the dark matter direct detection cross section.

We find that this is indeed possible, provided the NMSSM-specific coupling  $\lambda$  is relatively large,  $\lambda \sim 0.6$ . This coupling plays several rôles simultaneously: i) it determines the coupling of the neutralino-like dark matter to the NMSSM-specific CP-odd Higgs boson; ii) it determines the coupling of the CP-odd Higgs boson to charged higgsinos, whose loop leads to a large decay width into two photons; iii) it helps to increase the mass of the Standard Model-like CP-even Higgs boson. However, the mass of the NMSSM-specific CP-odd Higgs boson has to be close to 260 GeV (the s-channel pole) for a neutralino annihilation cross section into two photons equal to or larger than  $10^{-27} \text{ cm}^3 \text{ s}^{-1}$  (see [62]). On the other hand, no new particles or interactions beyond the NMSSM need to be introduced if the present hints for a 130 GeV gamma line from dark matter annihilation in our galaxy are confirmed.

In the next section we introduce the NMSSM and describe, which properties of the NMSSM allow to describe simultaneously all the above phenomena. We indicate a possible region in the parameter space, and discuss the range of possible direct detection cross sections and neutralino annihilation cross sections into two photons. Details of the Higgs and neutralino sector are presented for a typical benchmark point. Section 3 is devoted to a short summary and conclusions.

## 2 A 130 GeV Photon Line in the NMSSM

The NMSSM differs from the MSSM due to the presence of the gauge singlet superfield  $\hat{S}$ . In the simplest realisation of the NMSSM, the Higgs mass term  $\mu \hat{H}_u \hat{H}_d$  in the MSSM superpotential  $W_{\text{MSSM}}$  is replaced by the coupling  $\lambda$  of  $\hat{S}$  to  $\hat{H}_u$  and  $\hat{H}_d$ , and a self-coupling  $\kappa \hat{S}^3$ . Hence, in this version the superpotential  $W_{\text{NMSSM}}$  is scale invariant, and given by:

$$W_{\text{NMSSM}} = \lambda \hat{S} \hat{H}_u \cdot \hat{H}_d + \frac{\kappa}{3} \hat{S}^3 + \dots, \quad (1)$$

where the dots denote the Yukawa couplings of  $\hat{H}_u$  and  $\hat{H}_d$  to the quarks and leptons as in the MSSM. The NMSSM-specific soft SUSY breaking terms consist of a mass term for the scalar components of  $\hat{S}$ , and trilinear interactions associated to the terms in  $W_{\text{NMSSM}}$ :

$$-\mathcal{L}_{\text{NMSSM}}^{\text{Soft}} = m_S^2 |S|^2 + \left( \lambda A_\lambda H_u \cdot H_d S + \frac{1}{3} \kappa A_\kappa S^3 \right) + \text{h.c.} . \quad (2)$$

Subsequently we define the vacuum expectation values (vevs)

$$\langle H_u \rangle = v_u, \quad \langle H_d \rangle = v_d, \quad \langle S \rangle = s. \quad (3)$$

In terms of  $s$ , the first term in  $W_{\text{NMSSM}}$  generates an effective  $\mu$ -term with

$$\mu_{\text{eff}} = \lambda s. \quad (4)$$

Using the minimization equations of the potential in order to eliminate the soft SUSY breaking Higgs mass terms, the Higgs sector of the NMSSM is characterized (at tree level) by the six parameters

$$\lambda, \quad \kappa, \quad A_\lambda, \quad A_\kappa, \quad \mu_{\text{eff}}, \quad \tan \beta \equiv \frac{v_u}{v_d}. \quad (5)$$

The neutral CP-even Higgs sector contains 3 states  $H_i$ , which are mixtures of the CP-even components of the superfields  $\hat{H}_u$ ,  $\hat{H}_d$  and  $\hat{S}$ . Their masses are described by a  $3 \times 3$  mass matrix  $\mathcal{M}_{Hij}^2$ , where the dominant contribution to the singlet-like component  $\mathcal{M}_{H33}^2$  reads [43, 44]

$$\mathcal{M}_{H33}^2 \sim \kappa s (A_\kappa + 4\kappa s). \quad (6)$$

The neutral CP-odd Higgs sector contains 2 physical states  $A_i$ , whose masses are described by a  $2 \times 2$  mass matrix  $\mathcal{M}_{Aij}^2$  where  $\mathcal{M}_{A11}^2$  corresponds to the MSSM-like CP-odd Higgs mass squared. The dominant contributions to the singlet-like component  $\mathcal{M}_{A22}^2$  and the singlet-doublet mixing term  $\mathcal{M}_{A12}^2$  are given by

$$\mathcal{M}_{A22}^2 \sim -3\kappa s A_\kappa, \quad \mathcal{M}_{A12}^2 \sim \lambda(A_\lambda - 2\kappa s) \sqrt{v_u^2 + v_d^2}, \quad (7)$$

respectively [43, 44].

In the neutralino sector we have 5 states  $\chi_i^0$ , which are mixtures of the bino  $\tilde{B}$ , the neutral wino  $\tilde{W}^3$ , the neutral higgsinos  $\tilde{H}_d^0$ ,  $\tilde{H}_u^0$  from the superfields  $\hat{H}_d^0$  and  $\hat{H}_u^0$ , and the singlino from the superfield  $\hat{S}$ . Their masses are described by a symmetric  $5 \times 5$  mass matrix  $\mathcal{M}_{\chi^0 ij}$  given by

$$\mathcal{M}_{\chi^0 ij} = \begin{pmatrix} M_1 & 0 & -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_1 v_u}{\sqrt{2}} & 0 \\ & M_2 & \frac{g_2 v_d}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & 0 \\ & & 0 & -\mu_{\text{eff}} & -\lambda v_u \\ & & & 0 & -\lambda v_d \\ & & & & 2\kappa s \end{pmatrix} \quad (8)$$

where  $M_1, M_2$  are the soft SUSY breaking bino and wino mass terms. The lightest eigenstate  $\chi_1^0$  of the neutralino mass matrix (8) is considered as the dark matter particle. In the above basis, its decomposition is written as

$$\chi_1^0 = N_{11} \tilde{B} + N_{12} \tilde{W}^3 + N_{13} \tilde{H}_d^0 + N_{14} \tilde{H}_u^0 + N_{15} \tilde{S}. \quad (9)$$

The pair annihilation of  $\chi_1^0$  into two photons can be generated via a dominantly singlet-like CP-odd Higgs state  $A_S$  in the s-channel [9, 20, 21], see Fig. 1. (Similar diagrams with  $\chi^\pm$  replaced by (s)quarks or (s)leptons are numerically negligible.)

Now we turn to the masses and couplings of the particles and the corresponding regions in the NMSSM parameter space, which have all desired phenomenological properties. First we consider the dominantly singlet-like CP-odd Higgs state  $A_S$ . For a sufficiently large  $\chi_1^0$  pair annihilation cross section into two photons (and  $E_\gamma = M_{\chi_1^0} \sim 130$  GeV), we need

$$M_{A_S} \sim 2M_{\chi_1^0} \sim 260 \text{ GeV}, \quad (10)$$

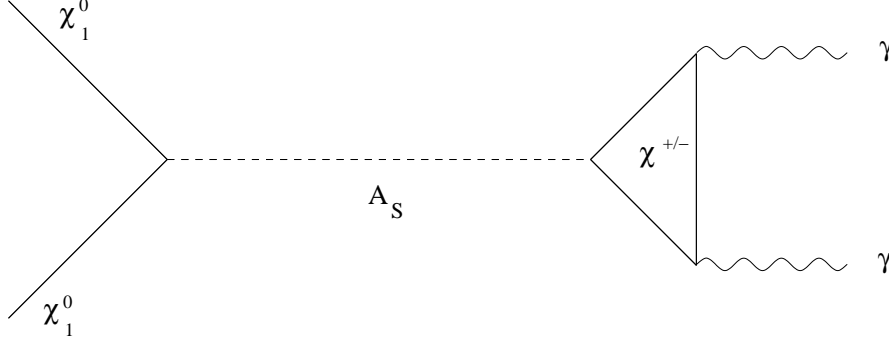


Figure 1: The dominant diagram for pair annihilation of  $\chi_1^0$  into two photons via a mostly singlet-like CP-odd Higgs  $A_S$  in the NMSSM.

which can be achieved by appropriate values of  $-3\kappa s A_\kappa$ . Moreover, the SU(2) doublet admixture of  $A_S$  must be small: Otherwise tree level diagrams similar to Fig. 1 but with  $A_S$  decaying directly into  $b\bar{b}$  (or into  $Z$  plus a light CP-even Higgs boson), lead to a too large pair annihilation cross section of  $\chi_1^0$  such that its relic density is below the WMAP bound. From the second of Eqs. (7) the mixing of  $A_S$  with the MSSM-like doublet is small for

$$A_\lambda \approx 2\kappa s. \quad (11)$$

Next we consider the dark matter particle  $\chi_1^0$ . It would have a large singlino component for small  $2\kappa s$ . However, from Eq. (6) and the first of Eqs. (7) one can derive

$$(2\kappa s)^2 \sim \mathcal{M}_{H33}^2 + \frac{1}{3}M_{A_S}^2; \quad (12)$$

from  $M_{A_S} \sim 260$  GeV and  $\mathcal{M}_{H33}^2 > 0$  it follows that  $2\kappa s$  cannot be small. Hence, assuming  $M_1 \lesssim M_2/2$  (assuming universal gaugino masses at the GUT scale), it follows that  $\chi_1^0$  has dominant bino and higgsino components. A priori large higgsino components seem desirable, given the required coupling of  $\chi_1^0$  to  $A_S$  in Fig. 1: This coupling is induced by the first term  $\lambda \hat{S} \hat{H}_u \cdot \hat{H}_d$  in the superpotential (1), which leads to a Yukawa coupling  $\lambda A_S \tilde{H}_u^0 \tilde{H}_d^0$ . Likewise, the coupling of  $A_S$  to the charginos  $\chi^\pm$  originates from the higgsino components  $\tilde{H}_u^+$ ,  $\tilde{H}_d^-$  of  $\chi^\pm$  and the Yukawa coupling  $\lambda A_S \tilde{H}_u^+ \tilde{H}_d^-$ .

However, too large higgsino components of  $\chi_1^0$  imply again a too small relic density; diagrams with charginos and neutralinos in the t-channel (and  $W^+W^-$  or  $ZZ$  in the final state), CP-even Higgs bosons in the s-channel etc. would lead to a too large pair annihilation cross section of  $\chi_1^0$ . Hence we end up with a dominantly bino-like  $\chi_1^0$ , but with non-zero (non-negligible) higgsino components. Its mass of 130 GeV has to follow from appropriate values of  $M_1$  and  $\mu_{\text{eff}}$ , with  $M_1 < \mu_{\text{eff}}$ .

Finally we require a SM-like CP-even Higgs boson  $H_{SM}$  with a mass  $M_{H_{SM}}$  near 125 GeV. Although its existence is not confirmed at present, it is interesting to investigate whether it could comply with the above properties of the neutralino and CP-odd Higgs sector. It has been known since a long time that the SM-like CP-even Higgs boson can be heavier in the NMSSM compared to the MSSM due to the NMSSM-specific coupling

$\lambda SH_u H_d$  [43–48], provided  $\lambda$  is large and  $\tan\beta$  is relatively small. Subsequently we choose corresponding values of  $\lambda$  and  $\tan\beta$  such that  $M_{H_{SM}} \sim 125$  GeV [49–59]. We find that the above properties in the neutralino and CP-odd Higgs sector imply that  $H_{SM}$  is the lightest CP-even Higgs state; the singlet-like CP-even Higgs state has a mass  $\gtrsim 200$  GeV. The scenario with a lightest singlet-like Higgs state and a next-to-lightest SM-like Higgs state (allowing for an enhanced branching ratio into  $\gamma\gamma$  [51, 53, 55, 56]) seems difficult to realize. Herewith we have sketched the interesting regions in the parameter space in (5).

An open question remains whether the dark matter particle can comply with the constraints from XENON100 on its spin-independent detection cross section:  $\chi_1^0$ -nucleon scattering is induced dominantly by  $H_{SM}$ -exchange in the t-channel [67], and the  $H_{SM}$ - $\chi_1^0$ - $\chi_1^0$  vertex is proportional to the product of the bino- and higgsino-components of  $\chi_1^0$  (from  $g_1 \times \text{bino} \times \text{Higgs} \times \text{higgsino}$  terms in the Lagrangian, where  $g_1$  is the  $U(1)_B$  gauge coupling). This issue will be studied below.

We have scanned the parameter space of the general NMSSM with help of the NMSSM-Tools package [68, 69], supplemented with suitably modified formulas for the cross sections for  $\chi_1^0 \chi_1^0 \rightarrow \gamma\gamma$  (and for  $\chi_1^0 \chi_1^0 \rightarrow Z\gamma$ ) from [2, 4]. MicrOmegas [70–72] is used for the calculation of the dark matter relic density and direct detection cross sections. For the latter we have to specify the strange quark content of the nucleons, i.e. the relevant sigma terms. We use the most recent values from [73] with, to be conservative, a value for  $\sigma_{\pi N}$  near the lower end of the  $1\sigma$  error bars:  $\sigma_{\pi N} = 40$  MeV,  $\sigma_0 = 39$  MeV.

For the soft SUSY breaking terms we made the following choices:

- Squark masses of 1.5 TeV, except for the left-handed squarks of the 3rd generation (1 TeV) and the right-handed top squark (300 GeV). The latter values are motivated by universal soft scalar masses at the GUT scale [57], and alleviate LHC constraints from direct SUSY searches due to the more complicated squark and gluino decay cascades involving the light stops.
- Trilinear soft susy breaking terms  $A_t = A_b = -1.1$  TeV.
- Slepton masses in the 140 – 500 GeV range such that the SUSY contributions to the anomalous muon magnetic moment are sufficiently large (inspite of low values of  $\tan\beta$ ), while slepton exchange in the t-channel of the pair annihilation cross section of  $\chi_1^0$  does not imply a too small relic density.
- Whereas we vary  $M_1$  in the 140 – 160 GeV range (see below),  $M_2$  and the gluino mass  $M_3$  are kept fixed at  $M_2 = 300$  GeV,  $M_3 = 800$  GeV for simplicity.
- Finally we use 173.1 GeV for the top quark pole mass.

Subsequently we impose the following phenomenological constraints:

- $M_{\chi_1^0} = 129 - 131$  GeV and  $\langle\sigma v\rangle(\chi_1^0 \chi_1^0 \rightarrow \gamma\gamma) > 10^{-27} \text{ cm}^3 \text{ s}^{-1}$  in order to obtain a photon line in agreement with the excess found in [30, 31].

- Upper bounds on annihilation cross sections into  $W^+W^-$ ,  $ZZ$ ,  $b\bar{b}$  and  $\tau\bar{\tau}$  channels from the Fermi LAT collaboration [28, 60] (see also [61, 62]), as well as bounds from PAMELA on the antiproton flux [63]. For the determination of these cross sections/fluxes we use micrOMEGAs2.4 [64].
- A relic density complying with the WMAP bound  $\Omega h^2 = 0.1120 \pm 0.011$  [35] (with  $2\sigma$  error bars).
- A SM-like Higgs boson with  $M_{H_{SM}} = 124 - 127$  GeV, as it was confirmed recently by the ATLAS and CMS collaborations [65, 66].
- Constraints from B-physics as implemented in NMSSMTools (which have actually no impact for the low values of  $\tan\beta$  considered here).
- A sufficiently large SUSY contribution  $\Delta a_\mu$  to the muon anomalous magnetic moment as implemented in NMSSMTools.
- Constraints from the absence of Landau singularities of the running Yukawa couplings below the GUT scale, and the absence of unphysical global minima of the Higgs potential.

We have found corresponding points in the NMSSM parameter space, both below and slightly above the present XENON100 bound on the spin-independent dark matter – proton cross section of  $\sigma(p)_{SI} \lesssim 1.2 \times 10^{-8}$  pb for  $M_{\chi_1^0} \sim 130$  GeV [36]. In Fig. 2 we show  $\sigma(p)_{SI}$  as function of  $M_1$  for a sample of such points, where we varied the parameters in (5) in the range  $\lambda = 0.6 - 0.615$ ,  $\kappa = 0.326 - 0.329$ ,  $A_\lambda = 240 - 400$  GeV,  $A_\kappa = -130 - (-60)$  GeV,  $\mu_{\text{eff}} = 230 - 445$  GeV,  $\tan\beta = 1.68 - 1.82$ .

In Table 1 we show the details (parameters, masses and relevant observables) for a sample point with  $M_1 = 150$  GeV. The couplings of  $H_1 \equiv H_{SM}$  to quarks, leptons, electroweak gauge bosons, gluons and photons are SM-like within  $\sim 5\%$ .  $R_{A_S}^{bb}$  denotes the coupling of  $A_S$  to  $b$ -quarks normalized to the one of a SM-like Higgs boson; its small value underlines its singlet-like nature.

The following remarks are in order: The larger  $M_1$ , the smaller one has to choose  $\mu_{\text{eff}}$  in order to maintain  $M_{\chi_1^0} \sim 130$  GeV. It follows that, for larger  $M_1$ , the higgsino component of  $\chi_1^0$  increases leading to a larger  $\chi_1^0\chi_1^0$  annihilation cross section. Hence, for too large  $M_1$ , the relic density falls below the WMAP bound.

On the other hand, for smaller  $M_1$  one has to choose larger values for  $\mu_{\text{eff}}$  implying a smaller higgsino component of  $\chi_1^0$ , which explains the decrease of  $\sigma(p)_{SI}$  in Fig. 2. However, simultaneously the coupling of  $A_S$  to  $\chi_1^0$  decreases as well. As a consequence, the mass  $M_{A_S}$  of  $A_S$  has to be closer and closer to the pole  $2M_{\chi_1^0}$  in order to obtain  $\sigma(\chi_1^0\chi_1^0 \rightarrow \gamma\gamma) > 10^{-27} \text{ cm}^3 \text{ s}^{-1}$ . In order to clarify the required tuning, we show  $\sigma(\chi_1^0\chi_1^0 \rightarrow \gamma\gamma)$  in Fig. 3 as function of  $M_{A_S}$  for the point listed in Table 1. (Note that the finite width  $\Gamma(A_S) \sim 1.6$  KeV, dominated by  $A_S \rightarrow \gamma\gamma$ , is not visible in Fig. 3. Due to the small couplings of  $A_S$  to quarks and leptons, the contributions of  $A_S$  in the s-channel to the annihilation cross sections into  $b\bar{b}$  and  $\tau\bar{\tau}$  final states are well below the Fermi LAT bounds. The annihilation cross sections into  $W^+W^-$  and  $ZZ$  originate from the second CP-even Higgs boson in the s-channel. The



antiproton flux has a maximum of  $\sim 2.47 \times 10^{-4} (\text{GeV m}^2 \text{ sr})^{-1}$  for an energy of  $\sim 2 \text{ GeV}$ , which is well below the PAMELA bound.)

We see that  $\sigma(\chi_1^0 \chi_1^0 \rightarrow \gamma\gamma)$  is larger than  $10^{-27} \text{ cm}^3 \text{ s}^{-1}$  only within a  $\sim 0.7 \text{ GeV}$  wide window of  $M_{A_S}$ . This required tuning becomes worse for lower values of  $M_1$ , and would be the price to pay for a possibly stronger constraint on  $\sigma(p)_{SI}$  from XENON100 in the future. (On the other hand, modifications of the present best estimates for the Higgs-nucleon coupling and/or the local dark matter density could alleviate the present constraints from XENON100.)

Finally we should add that diagrams similar to Fig. 1, but with one photon replaced by a  $Z$  boson, contribute to  $\sigma(\chi_1^0 \chi_1^0 \rightarrow Z\gamma)$  leading to an additional photon line with, for  $M_{\chi_1^0} \sim 130 \text{ GeV}$ ,  $E_\gamma \sim 114 \text{ GeV}$ . For the present scenario we find  $\sigma(\chi_1^0 \chi_1^0 \rightarrow Z\gamma) \sim 75\% \times \sigma(\chi_1^0 \chi_1^0 \rightarrow \gamma\gamma)$ . Such an additional line would be compatible with the structure observed in [32]. In any case, additional lines—also from  $\sigma(\chi_1^0 \chi_1^0 \rightarrow H\gamma)$  or interpreting the 130 GeV line as due to  $\chi_1^0 \chi_1^0 \rightarrow Z\gamma$ —can be interesting checks of such scenarios in the future [74].

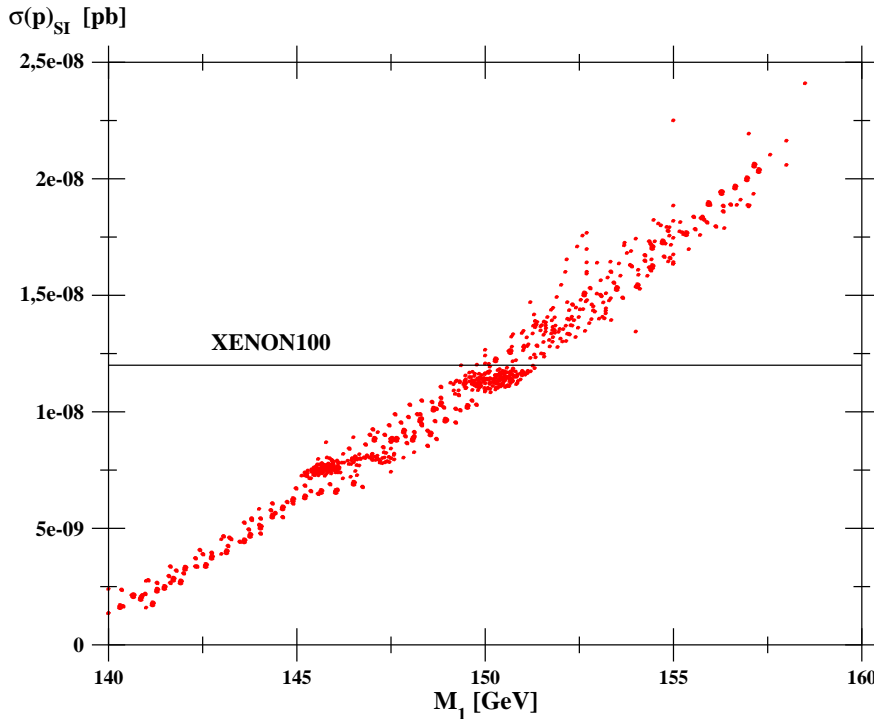


Figure 2:  $\sigma(p)_{SI}$  as function of  $M_1$  for a sample of points satisfying all other phenomenological constraints as indicated in the text. The horizontal line indicates the present bound from XENON100 for a 130 GeV dark matter particle, which holds for all points shown.



Parameters	
$\lambda$	0.61
$\kappa$	0.328
$A_\lambda$	267
$A_\kappa$	-114.1
$\tan\beta$	1.8
$\mu_{\text{eff}}$	269
$M_1$	150
left-h. slepton masses	150
right-h. slepton masses	160
$A_e = A_\mu = A_\tau$	500
Sparticle masses	
$m_{\tilde{g}}$	971
$\langle m_{\tilde{q}} \rangle$	1530
$m_{\tilde{t}_1}$	204
$m_{\tilde{t}_2}$	1034
$m_{\tilde{b}_1}$	1005
$m_{\tilde{\mu}_L}$	154
$M_{\chi_1^0}$	129.6
$M_{\chi_2^0}$	217
$M_{\chi_3^0}$	287
$M_{\chi_4^0}$	309
$M_{\chi_5^0}$	376
$M_{\chi_1^\pm}$	210
$M_{\chi_2^\pm}$	370

Higgs masses	
$M_{H_1}(=M_{H_{SM}})$	124.3
$M_{H_2}$	256
$M_{H_3}$	519
$M_{A_1}(=M_{A_S})$	258.9
$R_{A_S}^{bb}$	$3 \times 10^{-3}$
$M_{A_2}$	515
$M_{H^\pm}$	511
Components of $\chi_1^0$	
$N_{11}^2$	0.826
$N_{12}^2$	0.026
$N_{13}^2$	0.077
$N_{14}^2$	0.065
$N_{15}^2$	0.009
Observables	
$\Omega h^2$	0.11
$\sigma(p)_{SI} [10^{-8} \text{ pb}]$	1.21
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \rightarrow \gamma\gamma) [10^{-27} \text{ cm}^3 \text{ s}^{-1}]$	1.1
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \rightarrow Z\gamma) [10^{-27} \text{ cm}^3 \text{ s}^{-1}]$	0.8
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \rightarrow WW) [10^{-27} \text{ cm}^3 \text{ s}^{-1}]$	3.46
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \rightarrow ZZ) [10^{-27} \text{ cm}^3 \text{ s}^{-1}]$	0.26
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \rightarrow bb) [10^{-27} \text{ cm}^3 \text{ s}^{-1}]$	0.60
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \rightarrow \tau\bar{\tau}) [10^{-27} \text{ cm}^3 \text{ s}^{-1}]$	0.09
$\Delta a_\mu [10^{-10}]$	$6.5 \pm 3.0$

Table 1: Properties of a sample point with  $M_1 = 150$  GeV. Dimensionful parameters are given in GeV.  $R_{A_S}^{bb}$  denotes the coupling of  $A_S$  to  $b$ -quarks normalized to the one of a SM-like Higgs boson. The components of  $\chi_1^0$  are defined in Eq. (9). The value of  $\Delta a_\mu$  includes theoretical error bars.

### 3 Conclusions

In this paper we have shown that the simplest version of the NMSSM (with a scale invariant superpotential) could explain a 130 GeV photon line from dark matter annihilation with  $\sigma(\chi_1^0\chi_1^0 \rightarrow \gamma\gamma) > 10^{-27} \text{ cm}^3 \text{ s}^{-1}$  and, simultaneously, a 125 GeV SM-like Higgs boson. No additional fields or couplings need to be introduced. All constraints from WMAP on the relic density, from XENON100 on the direct detection cross section, from colliders and from precision observables can be satisfied.

However, the mass  $M_{A_S}$  of the singlet-like CP-odd Higgs scalar  $A_S$  has to satisfy accidentally  $M_{A_S} \approx 2M_{\chi_1^0} \sim 260$  GeV to a precision  $\lesssim 1$  GeV. This “fine-tuning” would

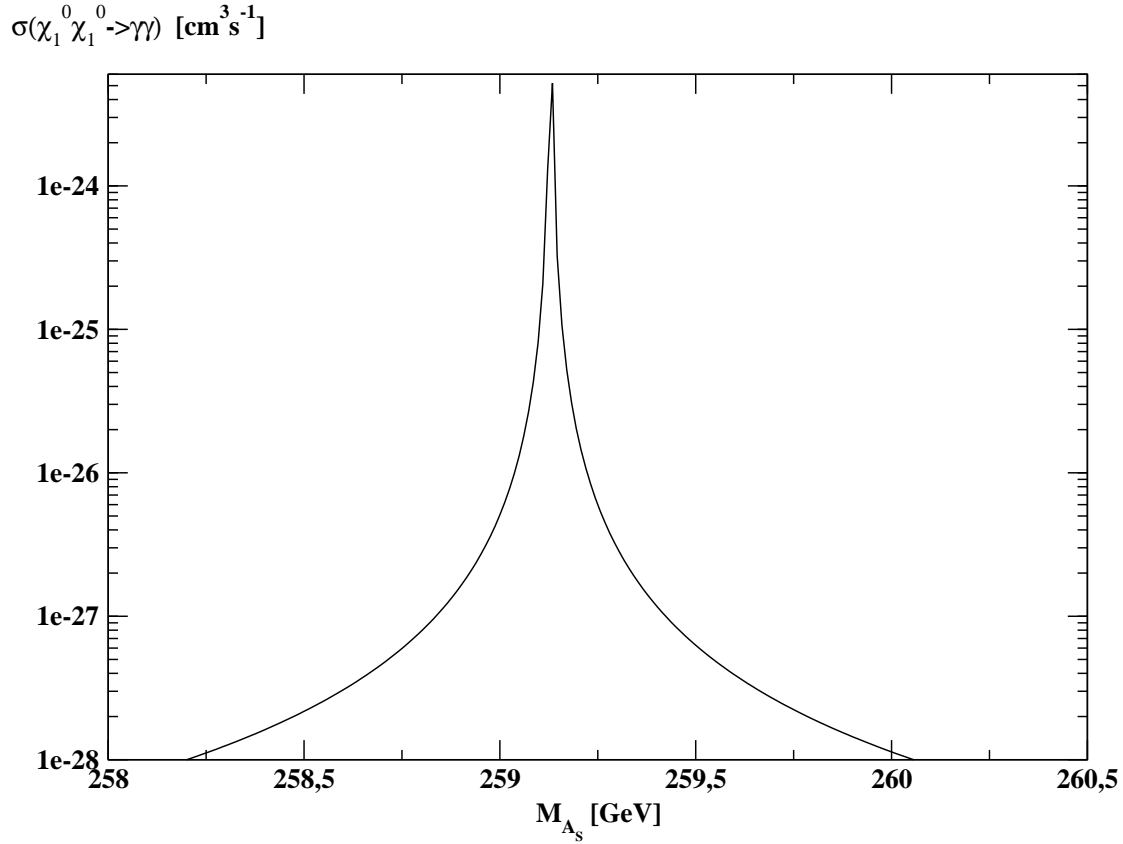


Figure 3:  $\sigma(\chi_1^0\chi_1^0 \rightarrow \gamma\gamma)$  as function of  $M_{A_S}$  for the point listed in Table 1.

become worse if bounds on the direct detection cross section become stronger (but could be relaxed otherwise).

Unfortunately a direct verification of this scenario at colliders through searches for a 130 GeV photon line seems hopeless: Due to the singlet-like nature of  $A_S$ , production cross sections for this state (as well as decay widths of sparticles or other Higgs bosons into this state) are too small. Only the mass of 130 GeV of the LSP  $\chi_1^0$  should fit the data, once searches for supersymmetry turn out to be successful. Of course, first of all the present hints for a 130 GeV photon line [29–32] need to be confirmed.

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